GROUND WATER RESOURCES OF PENNSYLVANIA

STANLEY W. LOHMAN

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BULLETIN W 7

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OF

PENNSYLVANIA

By

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of the U. S. Geological Survey

(Prepared in cooperation between the Geological Survey, United States Department of the Interior, and the Pennsylvania Topographic and Geologic Survey)

DEPARTMENT OF INTERNAL AFFAIRS
WILLIAM S. LIVENGOOD, JR., *Secretary*

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GROUND-WATER RESOURCES OF PENNSYLVANIA

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INTRODUCTION

A systematic investigation of the ground-water resources of the Commonwealth of Pennsylvania was begun in 1925 by the Pennsylvania Topographic and Geologic Survey in cooperation with the Geological Survey, United States Department of the Interior, and has continued to the present. The principal purpose of this investigation has been to provide accurate information as to the sources of ground water throughout the State, and as to the quantity, quality, and methods of recovery of these water supplies, in order that any individual, industry, or municipality may find the basic information necessary for a satisfactory and economical solution of its problems in regard to water supplies from wells or springs.

The investigations were made by four geologists of the Federal Survey under the general direction of G. H. Ashley, State geologist, and O. E. Meinzer, geologist in charge of the Division of Ground Water of the Federal Survey. The average annual expenditure by both Surveys during the period from 1927 through 1937 amounted to about

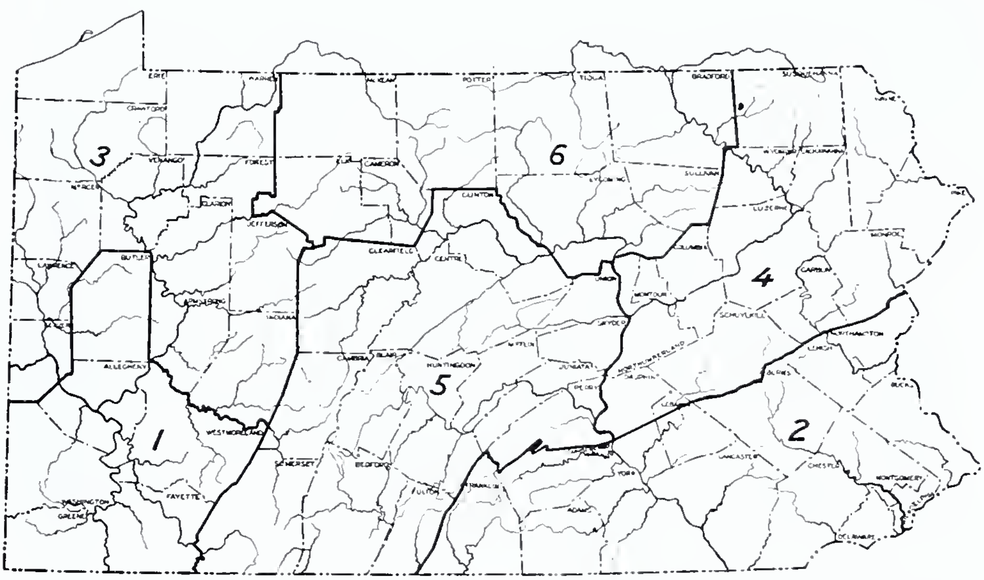

Figure 1. Index map of Pennsylvania showing areas covered by ground-water reports of the Pennsylvania Geol. Survey, 4th series.

1. Bull. W1: Piper, A. M., Ground water in southwestern Pennsylvania, 406 pp., 1 pl., 40 figs., 1933; 2. Bull. W2: Hall, G. M., Ground water in southeastern Pennsylvania, 255 pp., 7 pls., 7 figs., 1934; 3. Bull. W3; Leggette, R. M., Ground water in northwestern Pennsylvania, 215 pp., 9 pls., 15 figs., 1936; 4. Bull. W4: Lohman, S. W., Ground water in northeastern Pennsylvania, 312 pp., 7 pls., 18 figs., 1937; 5. Bull. W5: Lohman, S. W., Ground water in south-central Pennsylvania, 315 pp., 17 pls., 11 figs., 1938; 6. Bull. W6: Lohman, S. W., Ground water in north-central Pennsylvania, 219 pp., 11 pls., 13 figs., 1939.

$3,500, except during fiscal 1933, when it was only $943. Since 1937 the combined average annual expenditure has been about $900. The results of the investigations have been published by the State Survey in the six reports listed in the title of figure 1, each of which contains a general description of the ground-water resources of the area covered, a more detailed description of each county in the area, a colored geologic map, and tables of well and spring records and water analyses.

In 1931 a project was begun for obtaining systematic weekly records of ground-water levels in 36 representative observation wells in Pennsylvania, in cooperation between the State and Federal Surveys[1]. A history and description of this project has been published[2], and the complete records and water levels for all wells are being published annually[3]. The location of the 33 wells under observation at the close of 1939 is shown in figure 2.

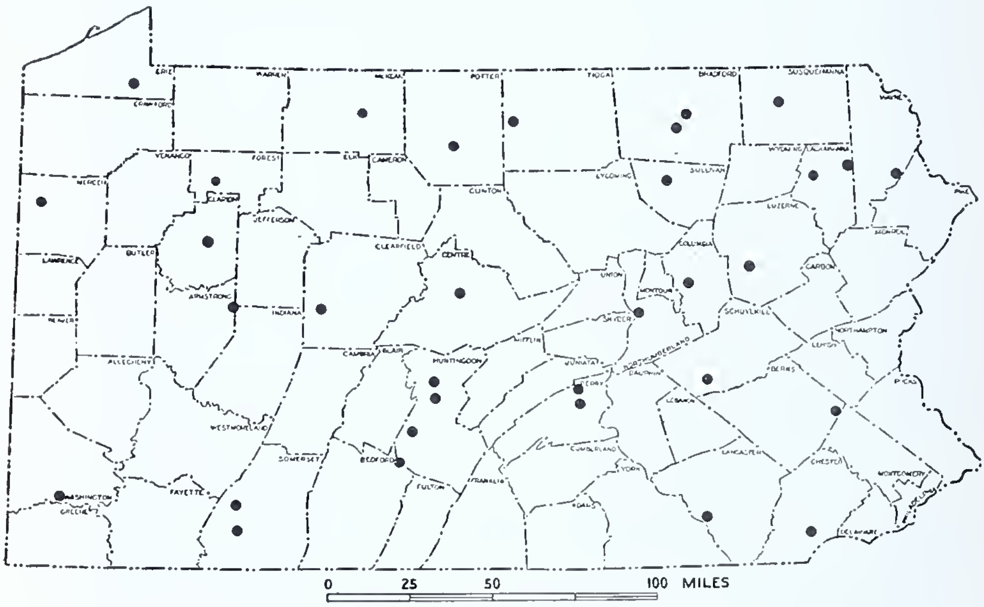

Figure 2. Map of Pennsylvania showing observation wells.

The purpose of this observation-well program is to provide a current inventory of the ground-water supply, to determine the magnitude and character of water-level fluctuations, and the rate at which the underground reservoirs are being replenished by rainfall or depleted by seepage from springs, by evaporation and plant transpiration, or by pumping from wells. As the low flow of the streams consists entirely of ground water, this study will also serve to establish the relation of ground-water levels to stream flow. The record is not yet of

[1] Lohman, S. W., Investigations of the fluctuations of the ground-water table in Pennsylvania: Am. Geophysical Union, 13th Ann. meeting, Trans., pp. 373-382, June, 1932.

[2] Water levels and artesian pressure in observation wells in the United States in 1935: U. S. Geol. Survey Water-Supply Paper 777, pp. 161-169, 1936.

[3] Water levels and artesian pressure in observation wells in the United States in 1936: U. S. Geol. Survey Water-Supply Paper 817, pp. 260-301, 1937.

Water levels and artesian pressure in observation wells in the United States in 1937: U. S. Geol. Survey Water-Supply Paper 840, pp. 347-364, 1938.

Water levels and artesian pressure in observation wells in the United States in 1938: U. S. Geol. Survey Water-Supply Paper 845, pp. 413-432, 1939.

sufficient length to permit a detailed study, but hydrographs of 27 of the wells together with some interpretive data are given in Pennsylvania Geological Survey Bulletins W3-W6 (fig. 1) and the unusually high ground-water level reached during the flood of March 1936 has been described.[4] It is planned to enlarge the program later to include records of water levels and pumpage in areas of heavy draft on the ground-water supply, such as the Philadelphia and Pittsburgh areas.

The need of a brief report to summarize the results of cooperative ground-water investigations in Pennsylvania by the State and Federal Surveys that extended over a period of 11 years was realized and suggested by George H. Ashley, State geologist. A working outline of the topics and illustrations for this report was prepared by O. E. Meinzer, geologist in charge of the Division of Ground Water of the Federal Survey. This report is based almost entirely upon the six bulletins listed in figure 1. Information on public water supplies in southeastern and southwestern counties was kindly supplied by H. E. Moses, chief engineer, Pennsylvania Department of Health.

POPULATION AND INDUSTRIAL DEVELOPMENT OF PENNSYLVANIA

Pennsylvania has a total land area of 45,302 square miles, and in 1940 had a population of 9,900,180—an average of 219 inhabitants to the square mile. The density of population ranges widely from as low as 13.7 inhabitants to the square mile in two of the mountainous heavily wooded counties, to 15,088 inhabitants to the square mile in Philadelphia. Philadelphia, the largest city in the State and the third city in the United States, had a population of 1,931,334 in 1940. Pittsburgh, the second largest city in the State, had 671,659 inhabitants. In 1940 three other cities had more than 100,000 inhabitants, 10 other cities had from 50,000 to 100,000, 77 other cities and boroughs had from 10,000 to 50,000, 252 communities had from 2,500 to 10,000, and 646 other communities had less than 2,500.

Pennsylvania ranks third among the 48 States in the total value of minerals produced annually, which in 1938 amounted to $472,773,327.[5] The four leading minerals in order of value were coal, petroleum, natural gas, and cement. Coal, natural gas, and petroleum are produced chiefly in the western plateau counties, but the anthracite comes entirely from northeastern Pennsylvania. Pennsylvania is highly industrialized. According to the Federal census of 1939, in that year 858,296 wage earners were employed to produce products valued at $5,475,925,482. Although some manufacturing is carried on in most counties, the bulk of the products were made in the following industrial areas, in order of importance: Philadelphia area, Pittsburgh area, Allentown-Bethlehem area, Reading area, Youngstown area (excluding larger part in Ohio), and the Scranton-Wilkes-Barre area. Leading manufacturing industries in order of annual value of products are: Iron and steel; foundry and machine shop products; electrical machinery, apparatus, and supplies; silk and rayon; knit goods;

[4] Lohman, S. W., Ground-water levels in Pennsylvania in 1936: Am. Geophysical Union, 18th Ann. Meeting, Trans., pp. 494-497, July, 1937.

[5] Minerals yearbook, 1940: U. S. Bureau of Mines, p. 38, 1940.

petroleum refining; steam-railroad cars, construction and repairs; and printing and publishing, newspaper and periodical.

In 1940 the total land area devoted to farming aggregated 14,594,134 acres—or about 50 percent of the total land area of the State. Farming is done mainly in the counties of low or moderate relief—some of the more mountainous counties being largely covered by forests. Thus the percentage of land area devoted to farming in 1940 ranged from only 6 percent in Cameron County to 84.2 percent in Greene County. The principal crops grown, in order of value, are: Corn, hay potatoes, wheat, oats, tobacco, barley, buckwheat, and rye.

WATER SUPPLIES FROM SPRINGS AND WELLS

Practically all the domestic water supplies in rural areas or small communities that have no public water works are obtained from springs or wells. At first springs and dug wells were used, but in later years drilled wells became more popular. At the present time most of the good springs are in use, particularly in the more highly settled areas.

Springs are widely used as sources of domestic and stock water in most parts of the State. The largest springs are located in the limestone valleys of central and southeastern Pennsylvania (fig. 6), however, and springs are probably most numerous in the glaciated parts of the State (fig. 11).

TABLE 1.

*Pennsylvania communities served by public water works, classified according to source of water and according to population.**

Source of water	Number of communities, by population in 1940: More than 1,000,000	100,000-1,000,000	50,000-99,999	10,000-49,999	5,000-9,999	1,000-4,999	Less than 1,000	Township supplies	Total	Largest communities supplied by each source	Population, 1940
Streams and lakes	1	4	8	48	57	127	174	41	460	Philadelphia Pittsburgh Scranton Erie Reading	1,931,334 671,659 140,404 116,955 110,568
Springs					2	14	117	3	136	Stroudsburg	6,186
Wells, mine shafts, and infiltration galleries				9	18	46	146	8	227	Aliquippa Duquesne	27,023 20,693
Wells, etc., and springs				2	3	30	61	4	100	Mahanoy City Mt. Carmel	13,442 17,780
Combination ground and surface water			2	6	12	45	43	5	113	Allentown Bethlehem	96,904 58,490
Total	1	4	10	65	92	262	541	61	1,036		

* See footnote, p. 5.

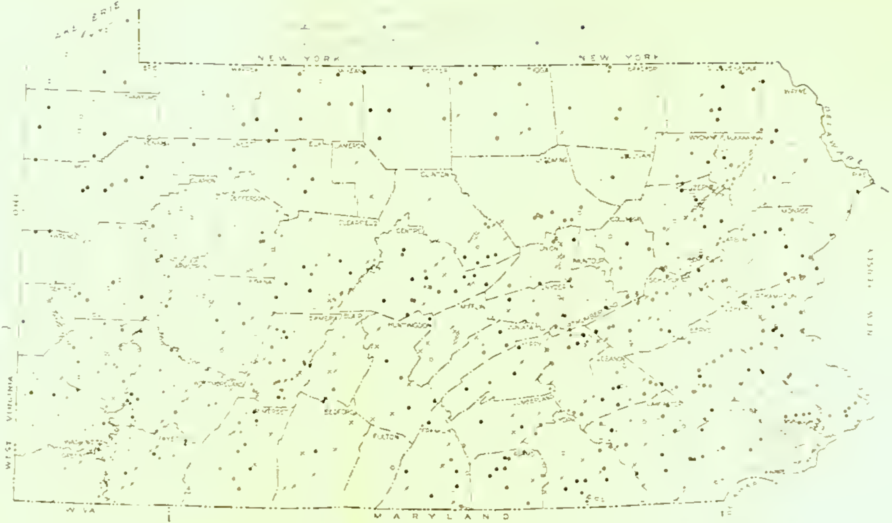

Figure . Map of Pennsylvania showing communities having public-water supplies. (Based in part on information furnished by the [illegible])

According to the best information available,[6] about 975 cities, boroughs, towns, villages, and institutions, and parts of about 61 townships are served by public water works, an aggregate of about 1,036 communities. Of the total number of communities, 463 are supplied wholly with ground water from wells, springs, mine shafts, or infiltration galleries; 113 are supplied with a combination of ground and surface water; and 460 are supplied exclusively with surface water from streams or lakes. The number of communities served by public water works classified as to the source of water and according to population is given in table 1; and their distribution throughout the State is shown in figure 3.

As given in the above table, the five cities with populations of more than 100,000 are supplied wholly by surface water; and 112 of the 162 communities having populations of 5,000 to 99,999 are also supplied wholly with surface water. Of the 803 communities with populations of from less than 1,000 to 4,999, however, 502 are supplied with ground water or by a combination of ground and surface water, of which 414 are supplied wholly with ground water. Thus ground water is relied upon to supply most of the smaller communities.

There are two principal reasons why most of the larger cities utilize surface water and the smaller places use ground water. The large cities require such large volumes of water that only exceptionally capacious ground-water reservoirs would be capable of supplying the demands—whereas the larger streams or lakes, near which most large cities are built, generally are capable of supplying large municipal needs. Surface water generally requires filtration and other treatment to remove turbidity, color, hardness, and/or other impurities. however, and this can be done economically only when large quantities of water can be treated each day. Ground water, on the contrary, generally is clear and requires no filtering; many ground waters do not require chlorination, but, in common with some surface waters, some ground waters require softening and/or treatment for the removal of iron or other undesirable constituents. Thus, where present in sufficient quantity, ground water is admirably adapted to the needs of small communities and a few of the larger ones. In most parts of Pennsylvania ground water is available in sufficient quantity and is of the requisite quality to meet the demands of the smaller communities.

As given in table 1, Aliquippa is the largest city supplied wholly with ground water. Most of the communities supplied with ground water have populations of less than 10,000. Allentown and Bethlehem are the largest cities supplied with a combination of ground and surface waters.

Ground water is used by many industries in Pennsylvania. The principal use of ground water is for cooling and condensing. Nearly all the ice or refrigerating plants, dairies, milk condensaries, and breweries use ground water for cooling, chiefly from drilled wells but

[6] No complete current list of public water supplies in Pennsylvania is available. The number and sources of public water supplies in northwestern, northeastern, and central Pennsylvania were taken from Bulletins W3, W4, W5, and W6 (fig. 1), and represent information collected between 1928 and 1936, and hence now may be somewhat out of date. The data for southeastern and southwestern Pennsylvania were supplied by H. E. Moses, chief engineer, Pennsylvania Department of Health, and are accurate as of January 1, 1940.

in part from springs. Ground water is also used for cooling or condensing by oil refineries, gas compressor stations, distilleries, and power plants. Some ground water from wells is used for air-conditioning theatres, office buildings, and stores, and this use of ground water is increasing—particularly in the larger cities. The great advantage of ground water for cooling is not only its relatively low temperature, but its uniform temperature throughout the year, which approximates the mean annual temperature of the air. The temperature of ground water ranges from 50°-55° in southern Pennsylvania to as low as 47°-48° in parts of northern Pennsylvania.

Considerable ground water is used in boilers. Some ground waters require no treatment for boiler use, but others must be treated for removal of hardness or of foam-producing constituents. Some ground water is used in locomotive boilers, but most water for this purpose is obtained from surface sources.

Considerable ground water is used for washing and processing by many different industries, such as breweries, bottling plants, tanneries, rubber factories, silk and woolen mills, laundries, rayon plants, paper mills, chemical plants, and canneries. The essential requirement of water for the paper industry is that it must be clear; thus any clear iron-free water is satisfactory, regardless of its hardness. Several large paper mills use water from large limestone springs, and some are supplied by wells. The rayon plant in Meadville is supplied from what are probably the strongest wells in the State. Laundries also require clear iron-free waters, but the water must also be soft. Some ground waters are usable for this purpose without treatment, others must be softened, and some are not suited owing to excessive hardness or iron content. Very large quantities of ground water pumped from mines are used for washing coal in the collieries, although in some places the mine water is too highly acid for this purpose. Some ground water is used for quenching in foundries.

GEOLOGY OF THE STATE

In Pennsylvania there is a great variety of rock formations, in general resting upon one another in the order of their age from the most ancient (pre-Cambrian) to the most recent. These rocks differ widely in origin, composition, and texture, and hence in the types and quantities of useful minerals that they contain and in the quantity and quality of ground water that they yield to springs and wells. The three principal kinds of rock—igneous, sedimentary, and metamorphic—are well represented and over a large part of the State these rocks have been intricately deformed and eroded. Thus the geology of the State is very complicated, but it has been deciphered to a large extent by the work of many geologists in the last hundred years, and it furnishes the key for determining the ground-water conditions.

The most ancient, or pre-Cambrian, rocks occupy a large part of the Piedmont province, in the southeastern part of the State (fig. 4). These rocks comprise in part crystalline igneous rocks, such as granite, diorite, monzonite, gabbro, etc., that were intruded in a molten condition into the earth's crust. Most of the ancient rocks, however,

are sediments and igneous rocks that have been metamorphosed by intense heat and pressure into gneiss, schist, quartzite, slate, serpentine, marble, and related types.

The pre-Cambrian rocks are overlain by a great succession of stratified formations of Paleozoic age, consisting of sandstone, conglomerate, shale, limestone, dolomite, coal, and other sedimentary rocks, the total thickness of which may amount to as much as 40,000 feet. The Paleozoic rocks are divided into several rock systems which are in the order of their age and superposition, as follows:* Cambrian, Ordovician, Silurian, Devonian, and Carboniferous systems. The Cambrian and Ordovician rocks consist chiefly of limestone and dolomite, but include also quartzite, sandstone, and shale. The Silurian, Devonian, and Carboniferous rocks consist chiefly of shale and sandstone,

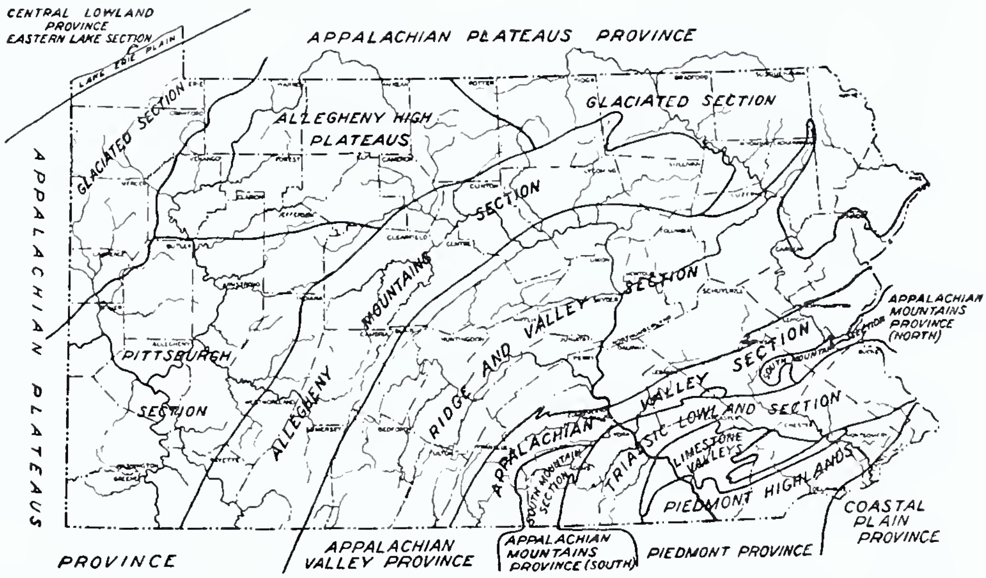

Figure 4. Map of Pennsylvania showing physiographic divisions (after Fenneman).

but also include beds of limestone. The Carboniferous system comprises three great rock series, which are in order of their age and superposition, the Mississippian, Pennsylvanian, and Permian. The Pennsylvanian series contains most of the valuable coal beds including both anthracite and bituminous coal.

The oldest Paleozoic rocks occur at the surface in parts of the Piedmont province, and all of the Paleozoic rock systems occur in the Appalachian Valley province, which lies between the Piedmont province on the southeast and the Appalachian Plateaus province on the northwest (fig. 4). In the Piedmont and Appalachian Valley provinces the rocks have been highly deformed by compressive crustal forces acting in a general direction from southeast to northwest. As the compression increased the strata were more intensely folded, and the upfolds or anticlines rose higher and steeper and in some places

* This report follows the classification of the U. S. Geological Survey. The Pennsylvania Geological Survey recognizes the Canadian system.

were overturned toward the northwest. In some places the once nearly horizontal beds now stand nearly vertical or are actually overturned. As some of the folds were overturned they were broken and one part over-rode the other, sometimes for considerable distances. Overthrust faults of this type are not uncommon, and show displacements of thousands of feet. Subsequent erosion first reduced these folded sediments to a nearly flat surface, or peneplain, and later, after renewed uplift, it exposed the hard sandstones in mountain ridges and reduced the shales and limestones to form valley areas. Thus the geologic structure is strikingly revealed in the present topography—particularly in the Ridge and Valley section, which comprises an alternate succession of narrow, even-crested ridges and broad or narrow valleys trending generally northeast (see frontispiece). The valuable anthracite beds were formed from soft coal by the intense folding and have been preserved from extensive erosion only in the deep synclinal troughs of northeastern Pennsylvania.

The Appalachian Plateaus province is underlain by a considerable thickness of Paleozoic rocks, but owing to the fact that the strata in this province lie nearly flat, only those of Devonian and Carboniferous age are exposed at the surface. Rocks of Pennsylvanian age, from which bituminous coal is mined extensively, form the larger part of the Plateaus province. Gentle folding of the strata has been adequate for the preservation of oil and natural gas in Devonian strata. The plateau has been deeply dissected in many places by streams, and the southeastern border of the plateau is marked by a bold escarpment known as the Allegheny Front.

A large area in the Piedmont province is underlain by shale and sandstone of Triassic age which aggregate about 23,000 feet in thickness. These sediments and adjacent older rocks are intruded by many dikes and sills of Triassic diabase. Beds of sand and clay of Cretaceous age occupy a small area in and near Philadelphia. Pliocene and Pleistocene terrace deposits of gravel, sand, and clay occupy small isolated areas in the southeastern corner of the State.

In the Pleistocene epoch northern Pennsylvania was covered several times by great ice sheets from the north, that extended as far south as the glacial borders shown in figure 11. During the retreat of the glaciers, the rock materials that had been accumulated by the advance were spread as an irregular mantle of glacial drift over large tracts in the northern part of the State. The swollen south-flowing streams that issued from the melting ice sheets transported an immense quantity of outwash material, partly filling many of the existing valleys. Other streams, particularly those draining northward, were dammed by the glaciers to form large lakes in which sediments accumulated. The numerous lakes and waterfalls in northern Pennsylvania were formed as a result of glaciation, as were many changes and reversals of drainage.

WATER IN THE ROCK FORMATIONS

PRE-CAMBRIAN ROCKS

Subdivisions and general features.—Rocks of pre-Cambrian age are exposed in several areas of southeastern Pennsylvania, as shown in figure 5. The oldest rocks are of Archean type, highly metamor-

phosed, and comprise the Baltimore gneiss and the Franklin limestone. The Baltimore gneiss is of sedimentary origin, but has been metamorphosed by intense folding and crushing and by intrusion of melted rocks from below. These ancient intrusives comprise the Hartley augen-gneiss, Lafayette serpentine, and Port Deposit gneiss.

Overlying the eroded surface of these rocks are more than 10,000 feet of less highly metamorphosed sediments comprising the Glenarm series. From oldest to youngest, the Glenarm series includes: The Setters formation, consisting of quartzite, schist, and gneiss, ranging up to 1,000 feet thick; the Cockeysville marble, 110-400 feet thick; the Wissahickon formation, consisting of schist with thin layers of quartzite and many metamorphic minerals, 8,000-10,000 feet thick; and the Peters Creek schist, comprising about 2,000 feet of quartzite grading into chlorite-sericite schist. The Cardiff conglomerate, comprising

Figure 5. Map of southeastern Pennsylvania showing areas of pre-Cambrian rocks.

several hundred feet of schist, conglomerate, and slate; and the overlying Peach Bottom slate, consisting of 1,000 feet of black slate used for roofing. These two formations formerly were included in the pre-Cambrian but are now regarded by some geologists as of probable Ordovician age.

In the South Mountain area, between Adams and Franklin Counties, thick flows of rhyolite and basalt lavas were poured out while the Glenarm sediments were being laid down to the east, and were later metamorphosed to greenstone and related types of rock.

The rocks described above are also intruded by post-Glenarm igneous rocks of both acidic and basic types.

To summarize, the pre-Cambrian rocks in southeastern Pennsylvania comprise a great thickness of complexly folded igneous and metamorphic rocks, including anorthosite, aporhyolite, granite, quartz diorite, quartz monzonite, pegmatite, peridotite, pyroxenite, gabbro, serpentine, greenstone, gneiss, graphitic gneiss, schist, slate, quartzite, marble, and other crystalline rocks.

Water supply.—The pre-Cambrian rocks generally furnish small supplies of good water. Most wells yield only a few gallons a minute—sufficient for domestic needs but generally not sufficient for public or industrial use. Most of the wells are less than 100 feet deep, and

are dependent upon the water in fractures and crevices in the zone of weathered rock. About half of the wells yield from 5 to 20 gallons a minute, and about one-fourth yield from 20 to 100 gallons a minute. A few wells yield less than 5 gallons a minute and a few yield more than 100 gallons a minute. Most of the water is soft and rather low in iron, particularly that from quartzite; but some is moderately hard and some contains iron in undesirable amounts.

CAMBRIAN AND ORDOVICIAN ROCKS

Unconformably overlying the pre-Cambrian rocks is a great thickness of Cambrian and Ordovician rocks, whose principal areas of outcrop are shown in figure 6. Broadly considered, these rocks may

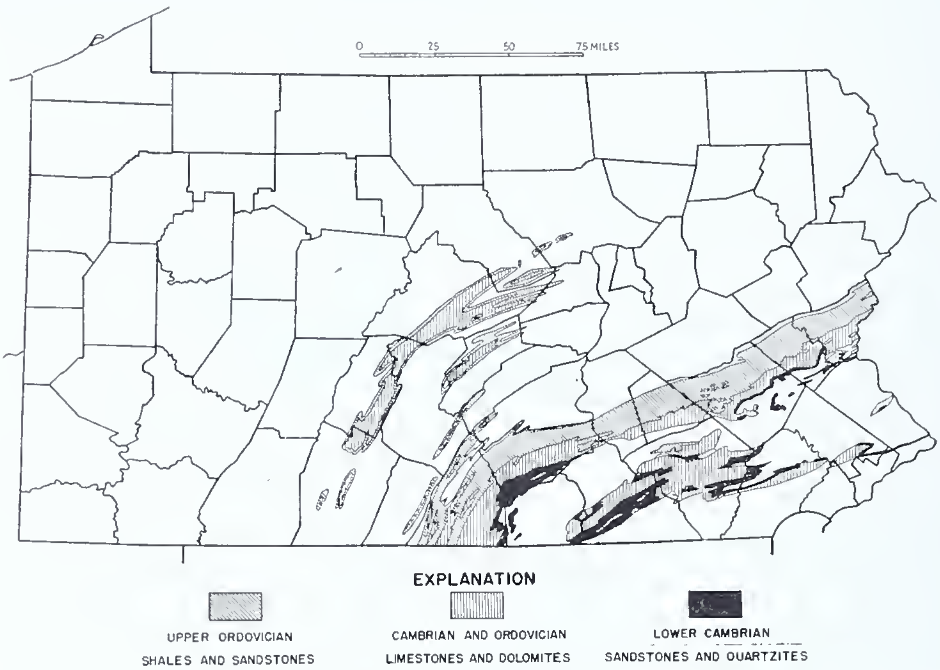

Figure 6. Map of Pennsylvania showing areas of Cambrian and Ordovician rocks. Youngest Ordovician rocks (Oswego sandstone and Juniata formation) are included with Silurian rocks in Figure 7.

be divided into three large groups (fig. 6) that differ markedly in their water-bearing properties; they are, from oldest to youngest: Cambrian sandstones and quartzites, Cambrian and Ordovician limestones and dolomites, and Upper Ordovician shale and sandstone.

LOWER CAMBRIAN SANDSTONES AND QUARTZITES

Subdivisions and general features.—Sandstones and quartzites of Lower Cambrian age crop out only in the southeastern part of the State (fig. 6), and comprise, in ascending order: the Loudoun formation, metamorphosed shale, sandstone, and conglomerate, 550 feet thick; the Weverton sandstone, sandstone and conglomerate, 750 feet thick; the Chickies and Hardyston quartzites, quartzite and conglomerate (Hellam member), 110 to 1,000 feet thick; the Harpers

phyllite or schist, shale, phyllite, schist, and quartzite (Montalto member), 1,000 to 3,000 feet thick; and the Antietam sandstone, 250 to 800 feet thick. In common with the pre-Cambrian rocks, these hard sandstones and quartzites generally form ridges or hilly areas.

Water supply.—The sandstones, quartzites, and conglomerates generally yield small but dependable supplies of water that are adequate for household or stock use. Most of the wells are less than 200 feet deep and obtain water from fractures. Most of the wells yield from 5 to 20 gallons a minute, but a few yield less than one gallon and a few yield as much as 200 gallons. The associated shales, phyllites, and schists, are poor water bearers and yield only meager supplies. The waters are generally low in dissolved mineral matter and exceptionally soft.

CAMBRIAN AND ORDOVICIAN LIMESTONES AND DOLOMITES

In southeastern and south-central Pennsylvania the Cambrian and Ordovician limestones and dolomites (fig. 6) constitute practically a single lithologic unit whose aggregate thickness ranges from 6,500 to 11,000 feet. Limestone, or calcium carbonate ($CaCO_3$) and dolomite, or calcium and magnesium carbonate ($CaCO_3.MgCO_3$), have similar appearance and water-bearing properties and are both known as limestone to drillers and laymen. The limestones form fertile valleys and lowlands, but some of the intercalated clastic formations, such as the Waynesboro and Gatesburg, form hilly areas in the limestone valleys. The succession and geologic names of these rocks in central Pennsylvania differ somewhat from those of southeastern Pennsylvania, and the rocks in each area are discussed separately.

Southeastern Pennsylvania.—The Tomstown dolomite is the oldest of these calcareous formations in and near Franklin County, and farther east the equivalent rocks are divided into the Vintage dolomite, Kinzers formation (dolomite and shale), and the Ledger dolomite. The Tomstown and equivalent formations range in thickness from 800 to about 1,500 feet. The Tomstown dolomite is overlain by the Waynesboro formation, comprising 600 to 1,750 feet of calcareous sandstone, red and purple shale, and subordinate beds of limestone, which is not found in the eastern part of the area. The next overlying formations are all limestones and comprise the Elbrook, 500 to 3,000 feet thick; Conococheague, 900 to 1,635 feet thick; Beekmantown (including Stonehenge limestone member), 500 to 2,300 feet thick; Stones River, 675 to 1,050 feet thick; and the Chambersburg, 100 to 750 feet thick. In the area between the Delaware and Lehigh Rivers, the limestone overlying the Beekmantown is the Jacksonburg ("cement-rock formation"), 250 to 700 feet thick. Throughout the Chester Valley the Conestoga limestone, which is apparently of Beekmantown age, overlies not only the Elbrook, but overlaps successively older beds down to and including the Harpers phyllite.

Central Pennsylvania.—In central Pennsylvania the oldest Cambrian formation exposed is the Waynesboro, about 300 feet of which has been faulted up in southern Blair County. The overlying Cambrian formations comprise the Pleasant Hill limestone, 500 feet thick; Warrior limestone, 1,250 feet thick; Gatesburg formation (dolomite, with

beds of sandstone or quartzite, silicified oolite, and limestone), 1,600 to 1,750 feet thick; and the Mines dolomite, 150 to 250 feet thick. The Beekmantown group, which includes most of the overlying Lower Ordovician series, comprises the Larke dolomite, 250 feet thick in places but absent locally; Stonehenge limestone, 700 feet thick at Bellefonte but absent locally; Nitanny dolomite, 1,000 to 1,250 feet thick; Axemann limestone, 500 feet thick in places but absent locally; and the Bellefonte dolomite, 1,000 to 2,200 feet thick. The overlying Carlim limestone is 100 to 400 feet thick. The Middle Ordovician rocks comprise the Black River group, which includes the Lowville limestone, 180 feet thick in places but absent locally; and Rodman limestone, 20 to 30 feet thick; and the Trenton limestone, 350 to 630 feet thick.

Water supply.—In general both the Cambrian and the Ordovician limestones and dolomites yield abundant supplies of water. These rocks are very dense, but being hard and brittle, they are generally more or less fractured, particularly in the areas of folded rocks, and tubular openings, or solution channels, are dissolved out along such fractures by percolating water charged with carbon dioxide. Solution channels range in size from minute openings to large limestone caverns, of which there are many in Pennsylvania.[1] The success of a well in limestone or dolomite depends upon the number, size, and water-bearing capacity of the solution channels encountered. Wells that encounter one or more water-filled channels generally yield large supplies of water. Most of the wells yield adequate supplies for domestic and stock use, and, of those equipped with large power-driven pumps, the yields range from less than 100 gallons a minute to more than 1,000 gallons a minute. Wells that fail to encounter solution channels, however, yield little or no water. Some poor wells in limestone can be improved by "shooting" with a properly placed charge of explosives in order to create crevices that may reach a nearby solution channel. If this fails, and if an adequate supply is not obtainable within a depth of 350 feet, it is more expedient to drill a new well at a nearby location. In Pennsylvania, however, the limestone generally contains many openings and very few dry holes are reported. Most of the wells obtain adequate supplies at depths less than 200 feet.

The largest known springs in Pennsylvania issue from tubular solution channels in limestone or dolomite, and are valuable assets to the large fertile limestone valleys. Boiling Springs, in Cumberland County, is the largest of these and yields 30 to 45 cubic feet a second, or 13,500 to 20,250 gallons a minute. Bellefonte Spring, in Centre County, yields 31 cubic feet a second, or about 14,000 gallons a minute. Some of these large springs run mills, others furnish all the water needed by communities or large industrial plants—particularly paper mills.

The shales, sandstones, and quartzites, which make up a small part of these formations, generally yield less water than the associated limestones and dolomites, and this is particularly true of the Kinzers and Waynesboro formations.

[1] Stone, R. W., Pennsylvania caves: Pennsylvania Geol. Survey, 4th ser., Bull. G3, 2nd edition, 143 pp., 68 figs., 1932.

The waters from these formations are generally moderately hard, but are softer and less concentrated than waters from the Silurian and Devonian limestones. Most of the waters are low in iron, and are satisfactory for most purposes.

UPPER ORDOVICIAN SHALES AND SANDSTONES

Subdivisions and general features.—The Martinsburg and Cocalico shales in southeastern Pennsylvania and the equivalent Reedsville shale in central Pennsylvania occupy wide valley areas adjacent to the limestone valleys (fig. 6), and range in thickness from 1,000 to 4,500 feet. They are typically black, brownish, gray, or greenish carbonaceous, fissile shales, but contain some beds of sandstone. Near the Delaware River the Martinsburg shale has been metamorphosed to black slate that is quarried extensively. The youngest Ordovician rocks, the Oswego sandstone and Juniata formation, are included with the Silurian rocks in figure 7 and are described with those rocks in the next section.

Water supply.—These shales generally yield small but dependable supplies of good water. Most of the water occurs in minute openings in the zone of weathered rock at depths of less than 200 feet; wells drilled deeper than 200 feet generally do not yield more water than the shallower wells. Most of the wells yield from 5 to 20 gallons a minute, few wells yield more than 50 gallons a minute, but a few do yield more than 100 gallons. The waters are moderately hard, but generally are softer than limestone waters. Some of the waters contain small quantities of hydrogen sulphide gas (H_2S) and some contain a noticeable amount of iron, but except for those that contain iron, these waters are entirely satisfactory for most purposes.

SILURIAN AND YOUNGEST ORDOVICIAN ROCKS

Subdivisions and general features.—The Silurian rocks together with the youngest Ordovician sandstones and shales crop out in cen-

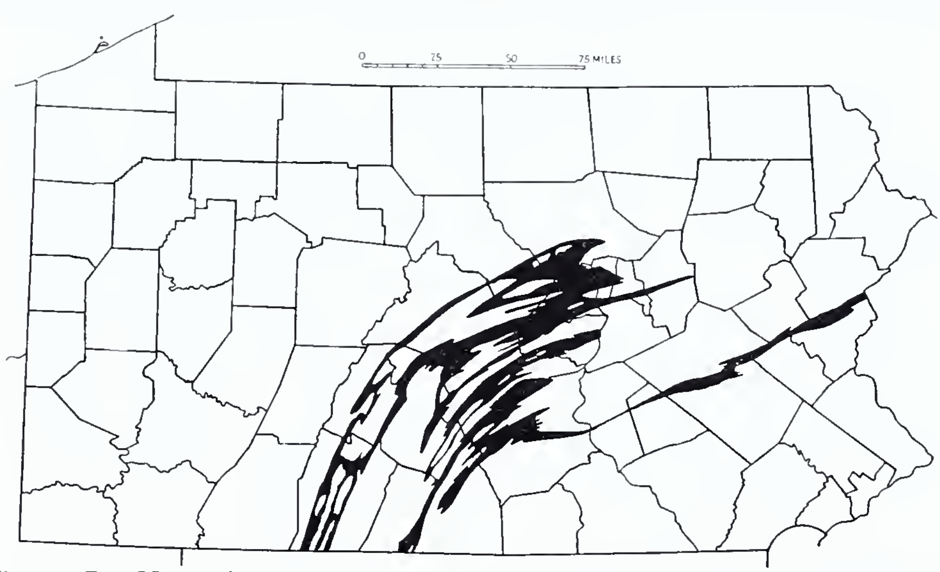

Figure 7. Map of Pennsylvania showing areas of Silurian and youngest Ordovician rocks.

tral and eastern Pennsylvania (fig. 7). The youngest Upper Ordovician rocks, the Oswego sandstone and Juniata formation, crop out in central Pennsylvania, but are absent east of the Susquehanna River, and locally sandstones equivalent to the Oswego are included with the underlying Martinsburg shale. The Oswego, where thickest, comprises 1,000 feet of brown to gray thick-bedded sandstone, but it is only 30 feet near Harrisburg. The Juniata comprises 68 to 1,200 feet of red or brown sandstone and shale.

The overlying Silurian rocks comprise: the Tuscarora quartzite, white to gray quartzite and quartz sandstone with coarse conglomerate at base locally, 100 to 850 feet thick; the Clinton formation, gray and greenish shale, greenish and red sandstone, some limestone and oolitic iron ore, 640 to 1,600 feet thick; the McKenzie formation, greenish and red shale interbedded with limestone, locally mainly limestone, 110 to 400 feet thick; and the Cayuga group. The three formations comprising the Cayuga group are: the Bloomsburg redbeds, chiefly red shale and sandstone, 50 to 500 feet thick in the central area, but 1,800 feet thick in eastern Pennsylvania, where it occupies almost the whole group; the Wills Creek shale (restricted), thin-bedded calcareous shale and limestone, 400 to 800 feet thick; and the Tonoloway limestone (included with the Devonian rocks in figure 8), 100 to 800 feet thick.

Water supply.—The Tuscarora and Oswego are hard resistant formations that form many of the high ridges in the Ridge and Valley section, and together with the Juniata and most of the Clinton, they form heavily forested mountainous areas containing only a few cabins, camps, and highway stands. Most of the few wells that tap these formations yield small to moderate supplies of very soft water, and several industrial and municipal wells in Blair and Monroe Counties yield from 60 to 350 gallons a minute of good water from sandstones in the Clinton. The shales of the Clinton generally do not yield more than 50 gallons a minute, even to deep wells, and large supplies have not been sought from the Oswego, Juniata, and Tuscarora. These rocks supply many small hillside springs, some of which are used to furnish soft water to houses and communities in the valleys below.

The McKenzie and Cayuga group underlies broad fertile valleys throughout much of central Pennsylvania, but locally where these rocks stand nearly vertical they occupy a narrow belt at the foot of high ridges. The McKenzie, Bloomsburg, and Wills Creek formations show great variations from place to place both in their composition and in their water-yielding capacity. Wells that encounter chiefly shale yield only small supplies, but those encountering limestone or highly calcareous shale generally yield moderately large supplies. The Bloomsburg yields only small supplies, but its water is generally soft. The Tonoloway limestone and the overlying Helderberg limestone (mapped together in most places in figure 8) yield moderately large supplies ranging up to more than 500 gallons a minute, and there are several large caverns and tubular springs in these rocks.

Except for the soft water in the Bloomsburg, the Cayuga waters generally are harder and more highly concentrated than any other

ground waters in the State, except for some of the deep-seated brines in the Plateaus province. Many of the waters in the Wills Creek shale are concentrated calcium sulphate waters ranging in hardness up to nearly 2,000 parts per million.

DEVONIAN ROCKS

Subdivisions and general features.—The Devonian rocks crop out over large areas in the central and northern parts of the State (fig. 8). The Lower, Middle, and Upper Devonian series are well represented in central and northeastern Pennsylvania and underlie the Carboniferous rocks in the Plateaus province, but only the Upper Devonian rocks crop out in northern Pennsylvania.

The Lower Devonian series comprises the Helderberg limestone, 150 to 415 feet thick, which overlies the Tonoloway limestone (Silurian); and the Oriskany group. The Oriskany group comprises at the base the Shriver chert (or formation), cherty thin-bedded

Figure 8. Map of Pennsylvania showing areas of Devonian rocks.

siliceous limestone, calcareous sandstone, or shale, ranging up to 300 feet thick but absent locally; and the Ridgeley sandstone, highly fossilferous calcareous sandstone, ranging up to 200 feet thick but probably absent locally.

The Middle Devonian rocks comprise the Onondaga formation, at the west dark green or bluish shale with some limestone, at the east dark gray cherty limestone underlain by hard sandy shale (Esopus), ranges up to 450 feet thick but is absent locally; the Marcellus shale, black fissile carbonaceous shale, with sandstone near middle locally, 100 to 800 feet thick; and the Hamilton formation, brown, yellow, olive-green, and black shale with sandstones that predominate locally, 500 to 1,500 feet thick.

The marine Upper Devonian rocks comprise the Tully limestone, Portage group, Chemung formation, and Conewango formation. In parts of eastern Pennsylvania the non-marine Catskill group occupies

the place of the post-Chemung, Chemung and part of the Portage, but the base of the Catskill phase of sedimentation becomes progressively younger toward the west until in McKean County it is of post-Chemung age and farther west in Warren County the Catskill is absent entirely and is replaced by the marine Conewango formation.

The Tully limestone is present only locally in central Pennsylvania where it ranges up to 240 feet in thickness. The marine Portage group ranges in thickness from 1,400 to 3,000 feet and comprises brownish-gray or olive-green shale and thin sandstones (Brallier) underlain by black and green shale (Harrell). Locally the Portage is dominantly sandstone (Trimmers Rock). The marine Chemung ranges in thickness up to 3,500 feet but locally is replaced entirely by the Catskill. It comprises drab, green, brown, and chocolate-colored shale and sandstone. The marine Conewango formation, which overlies the Chemung in and west of Warren County, comprises about 550 feet of greenish sandy shale and fine-grained sandstone with conglomerate near the middle. The rocks of the non-marine Catskill group range widely in thickness from 5,000 to 6,000 feet in parts of eastern and central Pennsylvania to a feather edge at the northwest. They comprise mainly red to brown shales, but contain red, brown, and gray sandstones (some crossbedded) and conglomerate. The Catskill comprises five fresh-water formations in northeastern Pennsylvania and is represented by two fresh-water and marine formations (Cattaraugus and Oswayo) in north-central Pennsylvania.

Water supply.—The quantity and quality of water yielded by the Devonian rocks varies widely among the many types of rock comprising this system. The Helderberg limestone yields moderate to large supplies of hard water to wells that encounter solution channels. The Ridgeley sandstone, though potentially a good water bearer, is utilized only in parts of Bedford, Blair, and Huntingdon Counties where it dips at a low angle and yields large supplies of good water. Elsewhere it occupies steep wooded ridges or is thin. The Shriver is not a good water bearer.

The Middle Devonian rocks generally yield only small supplies of water, with no appreciable increase with depth. Locally somewhat larger supplies are obtainable from sandstones in the Hamilton formation. The waters are moderately hard, and some, particularly from the Marcellus shale, contain hydrogen sulphide. A few waters contain iron in troublesome amounts.

The Tully limestone occurs only locally and is unimportant as a water bearer. The Portage group is a rather poor water bearer but adequately supplies many domestic wells. The waters generally are only moderately hard and superior to those from the Middle Devonian rocks. Most waters are relatively free of iron but a few from dark shale contain hydrogen sulphide.

In south-central Pennsylvania the Chemung formation and the Catskill group are rather poor water bearers, even to deep wells, but generally yield small supplies of good water that generally is soft or only slightly hard and is low in iron. In northeastern Pennsylvania and parts of north-central Pennsylvania the Catskill contains numer-

ous beds of sandstone that yield moderately large supplies of good water. In north-central Pennsylvania the Chemung yields moderately large supplies of water that is of good quality in some places but is salty in other places. Some of the waters are iron-bearing, and some contain hydrogen sulphide or natural gas. In northwestern Pennsylvania the Chemung and Conewango formations yield small to moderate supplies of good water, but locally yield salty water to deep wells.

CARBONIFEROUS ROCKS

The Carboniferous rocks are widely distributed over the State, as shown in figure 9, and comprise three great series: the Mississippian, Pennsylvanian, and Permian.*

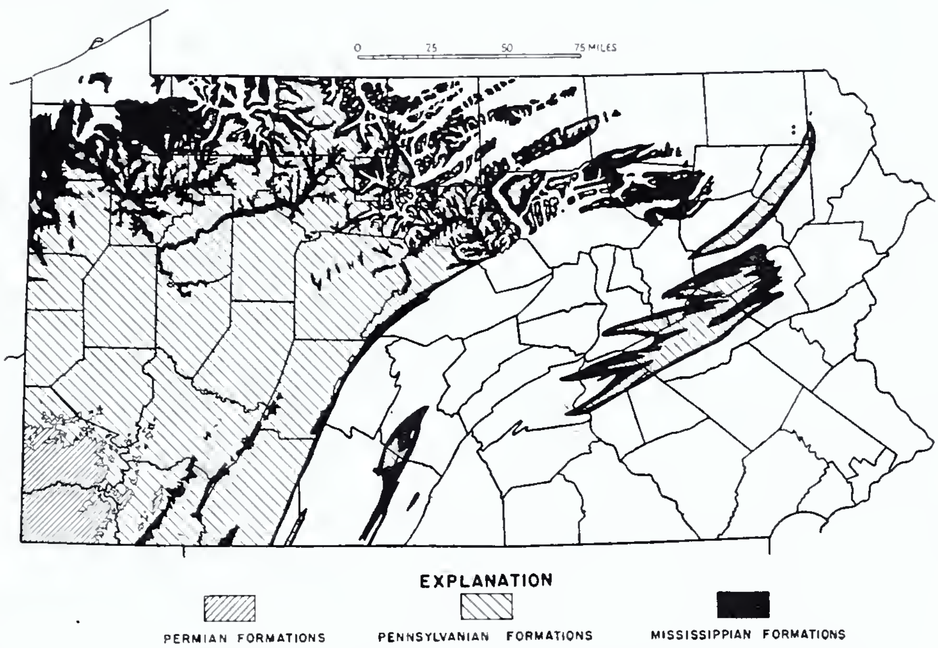

Figure 9. Map of Pennsylvania showing areas of Carboniferous rocks.

MISSISSIPPIAN SERIES

Subdivisions and general features.—The Mississippian series consists of the Pocono formation and Mauch Chunk shale. The Pocono formation consists largely of hard resistant sandstone and is one of the three principal mountain-making formations in the Ridge and Valley section. In northeastern Pennsylvania, where it is known as the Pocono sandstone, it is 500 to 1,600 feet thick and contains considerable conglomerate. In parts of north-central Pennsylvania only its base remains and is known as the Knapp formation, which is about 180 feet of conglomerate grading into sandstone. Along the Allegheny Front and in northwestern Pennsylvania it is known as the Pocono formation or group and locally is divisible into the Berea sandstone at the base, 20 to 200 feet thick; the Cuyahoga formation, shale with some sandstone and limestone, 5 to 310 feet thick; and the

* The Permian is being made a separate system under a new classification.

Burgoon sandstone, 65 to 450 feet thick. In south-central Pennsylvania the Pocono formation is 450 to 1,400 feet thick. In parts of western Pennsylvania the Pocono is overlain by the Loyalhanna limestone—20 to 60 feet of sandy limestone.

The overlying Mauch Chunk shale is 2,000 to 3,000 feet thick in parts of northeastern Pennsylvania, but, owing to profound erosion during most of succeeding Pottsville time, it was largely removed in the western part of the State where only 50 to 100 feet are present, and it is absent over some of the northwestern part of the State. Where thick it is mainly red shale with some beds of sandstone. To the west it contains considerable gray or greenish sandstone and locally in southern Pennsylvania it contains at the base the Greenbrier or Trough Creek limestone members.

Water supply.—Where exploited in eastern Pennsylvania, the Pocono yields large supplies of very good water, but in many parts of the Ridge and Valley section it is not accessible for development. In parts of the Plateaus province it yields large supplies of water, 300 to 600 gallons a minute locally, but the water generally contains considerable iron. Where under considerable cover in the Plateaus province it yields salty water. The Loyalhanna, Greenbrier, and Trough Creek limestones are unimportant as sources of water. The Mauch Chunk yields moderately large supplies of excellent water in northeastern Pennsylvania, small supplies of good water in south-central Pennsylvania, and in western Pennsylvania it yields from very small to moderately large supplies of water that locally may be hard and may contain considerable iron. It may also yield salty water where deeply buried.

PENNSYLVANIAN SERIES

Subdivisions and general features.—The Pennsylvanian series comprises four formations, the Pottsville, Allegheny, Conemaugh, and Monongahela. During Pottsville time 10,000 feet of sediments was deposited in Alabama, but owing to extensive erosion during this time in Pennsylvania, only 1,000 to 1,500 feet of sediments was deposited in eastern Pennsylvania and only 60 to 375 feet was deposited in western Pennsylvania. At the east it is mainly hard sandstone and coarse conglomerate, but to the west it is divisible into the Olean or Sharon conglomerate, Sharon shale and coal, Connoquenessing sandstone, Mercer shale and coal, and, at the top, the Homewood sandstone.

The overlying Allegheny formation consists mainly of shale, but contains some beds of sandstone, some limestone, and most of the workable coal beds in the State. It is extremely variable in lithology from place to place, but most of the individual beds have been named, particularly in the western part of the State. In western Pennsylvania it ranges in thickness from 220 to 370 feet; in eastern Pennsylvania the Allegheny and Conemaugh have an aggregate thickness of 1,000 to 2,000 feet.

The succeeding Conemaugh formation is 500 to 960 feet thick in western Pennsylvania and comprises a variable sequence of shale, clay, sandstone, thin coals (generally not workable) and thin beds of limestone, most of the units bearing names.

The Monongahela formation, the youngest of the Pennsylvanian rocks, is 200 to 400 feet thick in southwestern Pennsylvania, but only from 50 to 100 feet remain on scattered hilltops to the east and to the north. It comprises a variable sequence of limestone, shale, sandstone, and coal—much of which is workable, including at the base the Pittsburgh coal. Locally the formation is largely limestone, but in some places it is more sandy and contains red shale.

Water supply.—Where below drainage level the Pottsville generally yields moderate to large supplies of water, some wells yielding several hundred gallons a minute, but where it caps remnants of the plateau it may contain but little water. It yields water of good quality in eastern Pennsylvania, but in western Pennsylvania its waters generally contain considerable iron.

The Allegheny formation is a good water bearer in places distant from active coal mines, but near coal mines individual beds may be drained or may contain acidic, iron-bearing water. In favorable areas the shales yield small supplies and the sandstones yield from 50 to 300 gallons a minute. The waters generally are moderately hard and locally may contain considerable iron. At considerable depth waters from the Pottsville and Allegheny may be salty.

The Conemaugh formation yields small supplies to wells ending in shale and 50 to 250 gallons a minute to wells ending in sandstone. Some of the waters contain considerable iron but in general are of better quality than those of the Pottsville and Allegheny, except in eastern Pennsylvania, where most of the water in the Allegheny and Conemaugh has been drained by anthracite mines.

The Monongahela formation is not a productive water bearer, but as much as 25 gallons a minute is obtainable locally from limestone and lesser amounts from sandstone. The water in shallow wells is moderately hard, but at greater depth, in common with some Allegheny and Conemaugh waters, it may yield soft sodium bicarbonate water.

PERMIAN SERIES

Subdivisions and general features.—Rocks of Permian age crop out only in the southwestern corner of the State (fig. 9), and are represented by the Dunkard group comprising the Washington and Greene formations. The Washington formation is 275 to 440 feet thick and comprises a variable sequence of shale and sandstone, with thin-bedded limestones and several beds of coal that are mined locally. The Greene formation is 725 feet thick and consists of soft shale and shaly sandstone with some massive sandstones, a few thin limestones, and thin beds of coal that generally are not workable. Much of the shale is red.

Water supply.—The sandstones of the Permian yield moderate supplies locally, particularly the basal sandstone of the Washington formation, which yields as much as 65 gallons a minute. Smaller supplies are obtainable from the shales and limestones at shallow depths. The waters generally are of good quality, but are harder at shallow depth, and locally contain considerable iron.

TRIASSIC ROCKS

Igneous and sedimentary rocks of Triassic age crop out in southeastern Pennsylvania, as shown in figure 10. The sedimentary rocks are a part of the Newark group of Upper Triassic age and comprise an aggregate of about 23,000 feet of sandstone and shale, mostly reddish brown and cut in many places by dikes and sills of Triassic diabase.

Subdivisions and general features.—Near the New Jersey boundary, these rocks are divisible into the basal Stockton formation, chiefly coarse arkosic conglomerate, yellow and brownish red sandstone, and soft red shale, about 4,000 feet thick; the Lockatong formation, dark

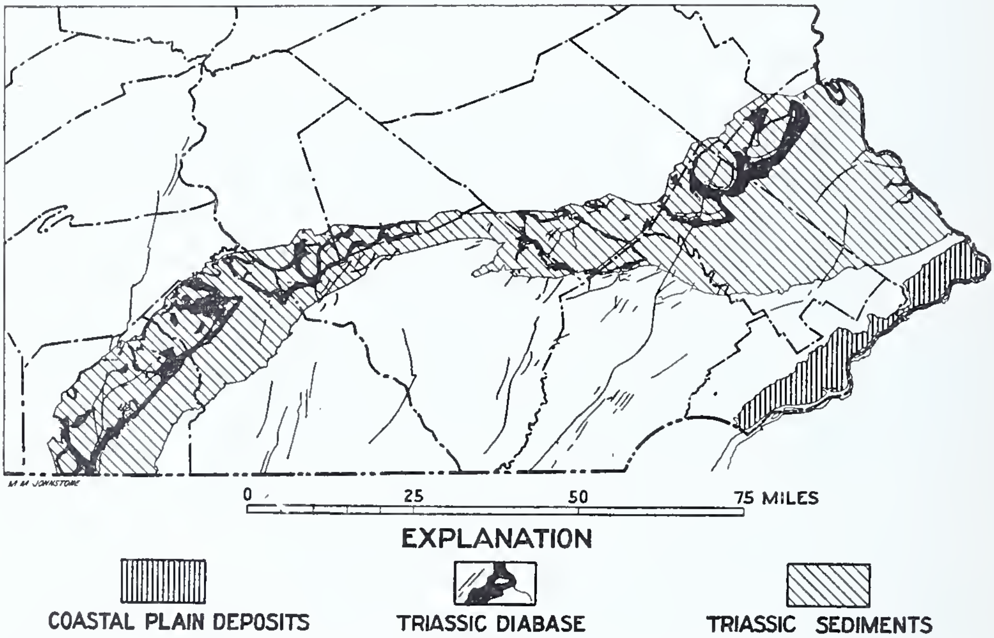

Figure 10. Map of southeastern Pennsylvania showing areas of Triassic rocks and Coastal Plain deposits.

hard shales and dark gray to green flagstones, 1,800 to 3,000 feet thick; and at the top the Brunswick shale, soft red, purple, green, and yellow shales with subordinate local sandstones, 12,000 to 15,000 feet thick.

To the west the Newark group comprises the New Oxford formation, red shale and sandstone with some arkose and conglomerate, 7,000 feet thick; overlain by the Gettysburg shale, which comprises three members with an aggregate thickness of 16,000 feet. The lower member consists chiefly of red shale and sandstone with some white sandstone, green, black, and yellow shale, and dark limestone, 7,500 feet thick. The middle member (Heidlersberg) consists chiefly of red shale and sandstone with some green, gray, and black shales, and many beds of hard gray to white sandstone, 4,800 feet thick. The upper member comprises about 3,500 feet of soft red shale, with some fanglomerate near the top.

Intruded into the Newark group and some of the adjacent older rocks are many dikes of Triassic diabase or trap rock, ranging in thickness from a few inches to a hundred feet or more, and many sills of the same rock ranging in thickness from a few feet to the Gettysburg sheet which is 1,800 feet thick. The dikes range in length from a few miles to more than 50 miles, and owing to their hardness, generally stand out as conspicuous ridges. The sediments intruded generally were hardened and baked by the heat of the diabase.

Water supply.—Small supplies of water are obtainable at moderate depth from the Triassic shales. The sandstones and particularly the conglomerates and fanglomerates yield as much as 200 to 300 gallons a minute. Some of the firmly cemented sandstones, however, yield very little water. The waters are generally hard and some contain objectionable amounts of iron.

The diabase is very difficult to penetrate with the drill and in general is a poor water bearer. Where weathered or fractured it yields a little water to shallow wells, but the fresh rock is very dense and yields practically no water. The waters range from soft to moderately hard and generally are low in iron.

COASTAL PLAIN DEPOSITS

Coastal Plain deposits of Cretaceous, Pliocene, and Pleistocene age crop out in a narrow belt along the Delaware River, as shown in figure 10, and some of the younger beds also crop out on hills to the west of this belt.

Subdivisions and general features.—The Cretaceous system is represented in southeastern Pennsylvania by the Patapsco and Raritan formations, which underlie part of the area shown in figure 10, but crop out only at a few places in the vicinity of Philadelphia. The Patapsco comprises coarse yellow sand at the base (Patuxent) overlain by highly colored, variegated clays. The overlying Raritan comprises 150 to 200 feet of light-colored discontinuous beds of sand and clay.

The Bryn Mawr gravel, believed to be of Pliocene age, caps hills in Montgomery, Philadelphia, Chester, and Delaware Counties, and consists of well rounded quartz pebbles more or less cemented into conglomerate.

The Brandywine formation, of Pleistocene age, comprises sand and gravel and occurs in Delaware County at a lower altitude than the Bryn Mawr gravel.

The youngest Coastal Plain deposits are the Sunderland, Wicomico, and Talbot formations, of Pleistocene age, which cap remnants of three successive terraces below the level of the Brandywine formation. These formations are composed of sand, gravel, boulders, clay, and silt.

Water supply.—The basal sand of the Patapsco formation (Patuxent) is an important source of water in the southern part of Philadelphia. The wells range in depth from 33 to 250 feet and are reported to yield from 30 to 800 gallons a minute. The Raritan formation yields some water but generally does not yield large supplies.

The thin scattered deposits comprising the Bryn Mawr and Brandywine formations generally are drained and are unimportant as sources of ground water.

The Pleistocene terrace deposits also are thin and scattered, and hence are not important as sources of water. Locally, however, yields from less than 1 gallon to 100 gallons a minute are obtained from wells ranging in depth from 22 to 160 feet.

GLACIAL DEPOSITS

During the Pleistocene epoch the northern part of Pennsylvania is known to have been covered three times by successive great ice sheets coming from the north which reached as far south as the glacial boundaries shown in figure 11. The three stages of glaciation in Pennsylvanian are named, in chronological order, the Jerseyan, Illinoian, and Wisconsin.

As the ice advanced, the soil and decomposed rock were scraped off and shoved along by the great weight and lateral force of the glacier. During the retreat of the glaciers, the rock materials that had been accumulated during the advance were left scattered over the surface as a veneer of drift or in piles or mounds known as moraines. The swollen south-flowing streams that issued from the melting ice sheets transported an immense quantity of material that partly filled many of the valleys both north and south of the drift borders. In many places streams were diverted by damming or complete filling of stream valleys, giving rise to waterfalls and to the numerous glacial lakes found in northern Pennsylvania. Large lakes formed by damming of north-flowing streams were partly filled with gravel, sand, and clay.

Glacial drift on the uplands.—The deposits referable to the oldest or Jerseyan stage of glaciation probably were entirely removed north of the Illinoian and Wisconsin borders, and south of these borders these deposits are represented merely by scattered boulders, hence they are unimportant as sources of ground water. Thin deposits of Illinoian till dropped by the ice are found south of the Wisconsin border, but are unimportant as sources of ground water. The Illinoian lake and stream deposits are more important and are discussed under the next subheading.

The Wisconsin drift left by the last retreat of the ice covers much of the bedrock north of the Wisconsin border except at places where islands of bedrock protruded above the ice or where it has been removed by subsequent erosion. The till dropped directly by the ice is unassorted and generally fine-grained, hence it yields only small supplies of water to shallow dug wells. Beds of stratified sand and gravel in the drift, however, yield small to moderate supplies of good water to many domestic and stock wells and to a few public-supply and industrial wells. The thickness of the drift and consequently the depth of the wells ranges widely, and in some places exceeds 300 feet. The depth to bedrock may differ by several hundred feet in nearby wells. Perforated casings, well screens, or gravel wall construction are required in many wells ending in glacial sand or gravel in order to develop sand-free water in adequate quantity.

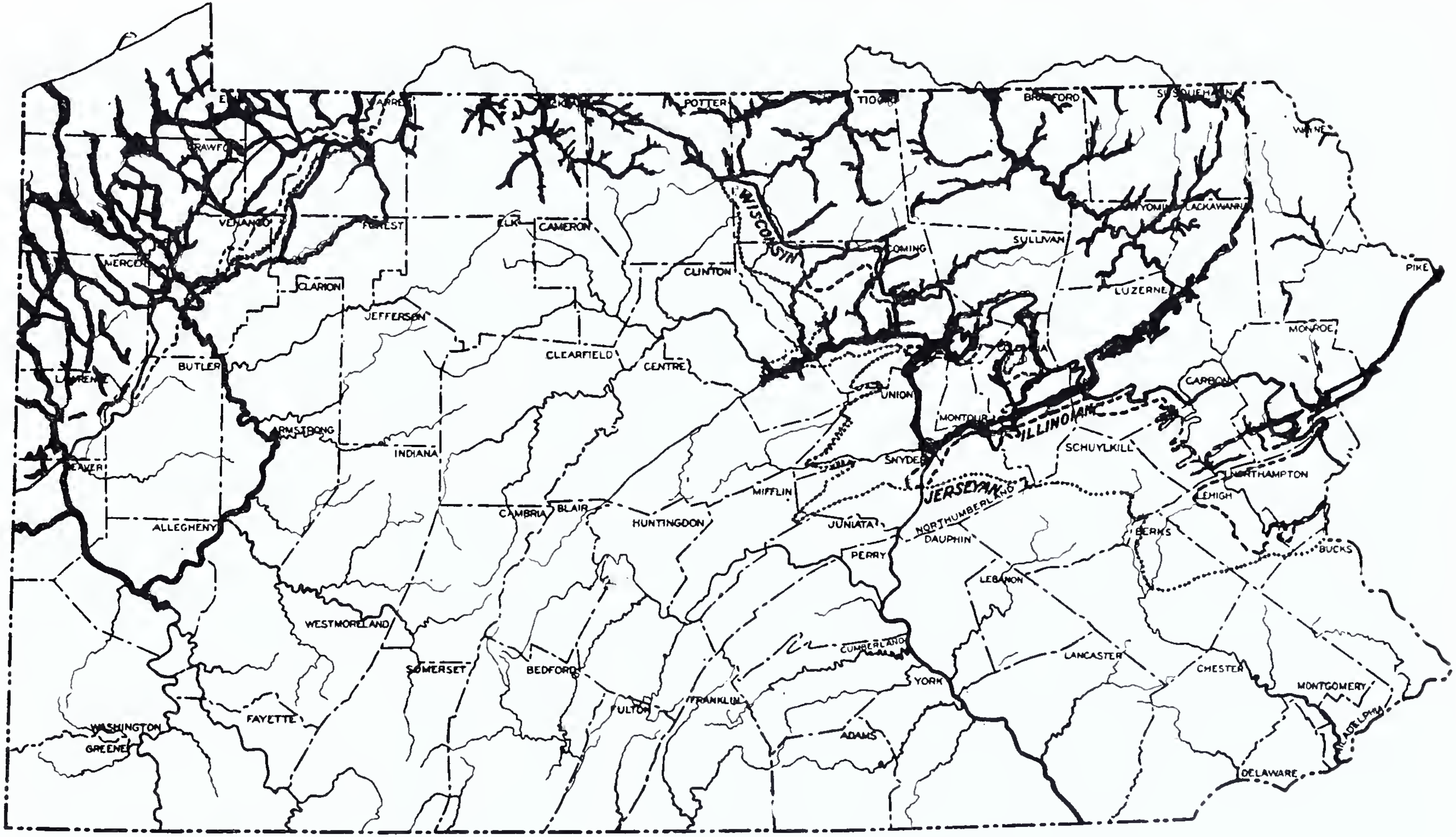

Figure 11. Map of Pennsylvania showing southern limits of glacial drift (after Leverett) and approximate location of principal glacial lake and stream deposits.

(From Pennsylvania Geol. Survey Bulletins W3, W4, and W6, and from notes and sketch maps made by the writer in 1930. Limits of deposits in the Wyoming Valley of Lackawanna and Luzerne Counties taken from maps by N. H. Darton.)

Glacial lake and stream deposits.—By far the most productive water-bearing materials in the State are the gravels and sands laid down in Illinoian and Wisconsin glacial lakes and streams. The known areal extent of these deposits is shown in figure 11. Thinner and less important deposits of comparable age but not directly the result of glaciation occur in some places south of the deposits shown on the map. It is apparent from the map that the glacial lake and stream deposits are not restricted to the area once covered by ice, but rather are restricted to valleys whose streams either carried away glacial flood waters or were dammed by glaciers. Most of the extensive glacial lake deposits are in the north-central part of the State and resulted from the damming of north-flowing streams. However, some of the lake deposits are the result of the damming of south-flowing streams—such as the West Branch of the Susquehanna River in Lycoming and Clinton Counties.

The character and thickness of the lake sediments and glacial outwash ranges widely from place to place, and may vary considerably within relatively short distances. In some places these deposits are 200 to nearly 500 feet thick. The material is not all water-bearing, for some of it is clay or silt, and some is very fine sand that tends to flow into wells unless special precautions are taken. In most places, however, it contains beds of coarse clean gravel or sand that are abundantly water-bearing, and in some places the entire thickness is water-bearing. If a large supply is sought, it is advisable to drill one or more test holes to bedrock, noting the thickness and character of each water-bearing bed. With this information it is generally possible to construct an efficient screened or gravel-wall well with openings of the proper size opposite the water-bearing beds.

Yields of 1,000 gallons a minute or more are not uncommon for wells in glacial gravel or sand in this State, and some wells yield several thousand gallons a minute with relatively small draw-down. The strongest known wells in the State are in very permeable outwash gravel at Meadville, Crawford County, and are reported to yield about 600 gallons a minute for each foot of draw-down.

The quality of water yielded by the lake and stream deposits ranges widely. In parts of northeastern Pennsylvania the water is very soft, low in dissolved mineral matter, and almost free of iron. In parts of north-central and northwestern Pennsylvania it is somewhat hard and locally contains iron in troublesome amounts.

QUALITY OF THE GROUND WATER

In general the mineral constituents of natural waters that determine their suitability for most purposes are the total dissolved solids, or concentration, the total hardness, and the content of iron. Locally, the concentration of certain other constituents such as sodium chloride (common salt) may limit the usefulness of a water, as described below.

Waters with less than 500 parts per million * of total dissolved solids generally are entirely satisfactory for domestic use, except for

* One part per million is equivalent to 1 pound of substance per million pounds of water. One gallon weighs 8.33 pounds; one part per million equals 8.33 pounds per million gallons. 17.118 parts per million equal one grain per gallon.

the difficulties resulting from their hardness or occasional excessive iron content. Waters with more than 1,000 parts per million are likely to contain enough of certain constituents to produce a noticeable taste or to make the water unsuitable in some other respects. However, some waters that contain more than 1,000 parts per million are satisfactory for domestic use and for some industrial uses, such as cooling.

The hardness of a water is commonly recognized by the increased amount of soap needed to produce a lather, and by the curdy precipitate that forms before a permanent lather is obtained. The constituents that cause hardness (mainly calcium and magnesium) are also the active agents in the formation of scale in steam boilers and tea kettles. Water with a hardness of less than 50 parts per million is generally rated as soft, and its treatment for the removal of hardness is rarely justified. Hardness between 50 and 150 parts per million does not seriously interfere with the use of water for most purposes, but it does slightly increase the consumption of soap, and its removal by a softening process is profitable for laundries and certain other industries. Treatment for the prevention of scale is necessary for the successful operation of steam boilers using waters in the upper part of this range of hardness. Hardness of more than 150 parts per million is noticed by anyone and where the hardness is 200 or 300 parts per million it is common practice to soften water for household use.

If a water contains much more than 0.1 part per million of iron, the excess may separate out after exposure to the air and settle as the reddish sediment common in many well waters in Pennsylvania. Iron stains cooking utensils and bathroom fixtures, and in certain industries may cause serious trouble owing to staining, as in the manufacture of white paper, the rayon and tanning industries, and in laundries. Iron generally can be readily removed by simple aeration and filtration, or by the methods used in softening water.

In the six bulletins on the ground water of Pennsylvania (fig. 1) are given the results of more than 600 chemical tests or examinations of typical ground waters collected from springs and wells throughout the State and from most of the principal geologic units. From these tests, most of which were made in the Quality of Water Laboratory of the Federal Geological Survey, was prepared the following table giving the total dissolved solids, total hardness, and iron in typical ground waters of Pennsylvania expressed in percentage of total number of waters examined and classified as to geologic source.

The next table indicates that 88 per cent of the waters examined contained less than 500 parts per million of total dissolved solids, and hence are suitable for most purposes. Twenty-five percent of the waters contained not more than 100 parts per million. Eighty-five percent of the waters had a hardness not exceeding 250 parts per million; 25 percent had a hardness of not more than 50 parts. The softest and least concentrated waters are those from the Lower Cambrian sandstones and quartzites and from the Clinton, Tuscarora, Juniata, and Oswego formations—which are also mainly sandstone and quartzite. The hardest waters are those from the limestones and calcareous shales of the Cayuga group (Silurian). In southwestern Pennsylvania many water-bearing beds of Pennsylvanian and Permian age contain soft

TABLE 2.

Total dissolved solids, total hardness, and iron in typical ground waters of Pennsylvania, expressed in percentage of total number of waters tested or examined and classified as to geologic source.

(Based on results in Pennsylvania Geological Survey Bulletins W1 to W6)

Geologic source	Number of tests	Total dissolved solids: Not more than 100 p.p.m.	Total dissolved solids: 101 to 500 p.p.m.	Total dissolved solids: More than 500 p.p.m.	Total hardness: Not more than 50 p.p.m.	Total hardness: 51 to 250 p.p.m.	Total hardness: More than 250 p.p.m.	Iron: Less than 0.1 p.p.m.	Iron: 0.1 to 1.0 p.p.m.	Iron: More than 1.0 p.p.m.
Recent alluvium	16	6	81	13	12	63	25	50	31	19
Glacial drift, including lake and stream deposits	92	35	56	9	33	58	9	64	28	8
Cretaceous deposits	2	0	50	50	0	0	100	50	50	0
Triassic rocks	37	24	64	11	22	51	27	46	43	11
Permian rocks	11	0	82	18	0	73	27	0	91	9
Pennsylvanian rocks	131	12	66	22	18	63	19	20	44	36
Mississippian rocks	74	24	70	6	30	69	1	34	30	36
Upper Devonian rocks	71	27	62	11	24	72	4	69	30	1
Middle Devonian rocks	19	26	63	11	22	67	11	68	16	16
Lower Devonian rocks	10	30	50	20	20	60	20	80	10	10
Cayuga group	23	9	70	21	9	30	61	82	13	5
Clinton, Tuscarora, Juniata, and Oswego formations	11	73	18	9	64	27	9	82	9	9
Reedsville and Martinsburg shales	11	27	73	0	27	73	0	36	55	9
Cambrian and Ordovician limestones and dolomites	47	4	85	11	2	66	32	60	38	2
Lower Cambrian sandstones and quartzites	10	90	10	0	80	20	0	50	30	20
Pre-Cambrian rocks	46	54	44	2	52	44	4	28	50	22
All rocks	611	25	63	12	25	60	15	47	35	18

sodium bicarbonate water at intermediate depths, but harder calcium bicarbonate water at shallow depths. The soft waters are believed to result from natural softening produced by natural base-exchange silicates in the rocks.

Forty-seven percent of the samples contained less than 0.1 part per million of iron; 35 percent contained from 0.1 to 1.0 part—sufficient in most of these waters to be noticeable; and 18 percent contained more than 1.0 part—sufficient to limit the usefulness of the water for certain purposes. The table indicates that many of the formations are relatively free of iron and that iron is most abundant in waters from the Pennsylvanian rocks. A part of the iron in the waters of the Pennsylvanian rocks, possibly a large part, results from the decomposition of pyrite (iron sulphide) associated with the numerous beds of coal contained in this series of rocks. Locally near active coal mines acid water also results from the decomposition of pyrite.

In parts of the Plateaus province of western and northern Pennsylvania the ground waters at shallow or moderate depths are fresh whereas those at greater depth, below drainage level, particularly in down-folds of the rocks called synclines, may be brackish or salty. Some of these deep-seated waters are brines that are more highly concentrated than sea water. Such salt water or brine is believed to be connate water—sea water that became entrapped in the marine sediments at the time of deposition and subsequently concentrated by expulsion of part of the water and solution of rock minerals or diluted by the percolation of rain water. These brines are preserved in the Plateaus province where there has been little or no deep-seated circulation of ground water, but have been largely removed by flushing and dilution in the central and southeastern parts of the State where the rocks are highly folded and faulted.

QUANTITY OF THE GROUND WATER

The sand and gravel in the glacial lake and stream deposits are undoubtedly the most productive water-bearing materials in the State, and yield as much as several thousand gallons a minute to properly constructed wells in favorable areas. In the vicinity of Philadelphia relatively large supplies are obtainable from sand and gravel of Cretaceous age, and recent sand and gravel yields fairly large supplies in parts of the State.

The Cambrian and Ordovician limestones yield large supplies (500 to more than 1,000 gallons a minute) to wells that tap water-filled solution channels, but may yield little or no water to wells that penetrate dense rock. Relatively few wells in these rocks are failures, however. Locally, moderately large yields are obtained from Silurian and Devonian limestones.

Next to sand and gravel, perhaps limestone, sandstone, and to a lesser extent conglomerate, are the most productive water-bearing rocks in Pennsylvania, and are found in most of the rock systems. The most productive sandstones are those of Mississippian and Pennsylvanian age—some of which yield 500 to 800 gallons a minute. The sandstones of the Pocono and Pottsville formations are especially productive, but large yields are also obtained from sandstones in the

Mauch Chunk, Allegheny, and Conemaugh formations. The Silurian and Devonian sandstones in general are less productive, but locally yield 100 to 300 gallons a minute. Triassic sandstones and conglomerates yield large supplies locally, but only small supplies in some places.

The Cambrian quartzites and sandstones generally yield small to moderate supplies, as do the Permian sandstones. The crystalline rocks generally yield only small supplies, but where they are deeply fractured or weathered, somewhat larger supplies are obtained. Some, like the Triassic diabase, are very poor water bearers.

Shale is perhaps the most abundant constituent of most of the formations in Pennsylvania. The yield of wells ending in shale ranges widely. Most shales yield water in appreciable quantity only in the weathered and fractured zone extending to depths of 50 to 200 feet. Most wells in the softer shales yield less than 50 gallons a minute—even deep wells. The sandy or slaty shales yield somewhat larger supplies, and some "slates" in the Pennsylvanian series yield more than 100 gallons a minute. Some shales are very tight and yield little or no water. Some wells obtain small supplies of water from coal, which, like shale, contains some water in joints and bedding planes.

Additional large developments of ground water can best be obtained from the glacial lake and stream deposits in the northern part of the State (fig. 11), from the Cambrian and Ordovician limestones and dolomites (fig. 6), or from areas underlain by thick sandstones—particularly those of Mississippian and Pennsylvanian age (fig. 9).

METHODS OF RECOVERY

Springs were eagerly sought after by the early settlers in Pennsylvania—particularly in the fertile limestone valleys where large springs abound. However, there were not enough suitable springs for all and some settlers had to dig wells. It was not difficult to dig wells by hand in valleys in which the water lay within 10 to 20 feet below the surface, but some wells in hilly country were hand dug to depths of 100 feet or more and required much hard and dangerous work. Although many dug wells are still in use today, particularly in rural sections, practically all of the wells constructed in recent years are drilled wells, caisson wells, and infiltration galleries.

Springs.—The yield of many springs, particularly small springs, generally can be increased by carefully cleaning them out and sometimes by excavating the soil and rock in the vicinity. A cut-off wall of masonry or concrete is helpful in concentrating the flow and in providing adequate storage. The reservoir thus created may be protected with a ventilated cover or roof and provides a convenient and protected intake for a gravity or pump pipeline. Some springs situated in low places are equipped with pumps or hydraulic rams for lifting the water to the house or barn.

Infiltration galleries.—An infiltration gallery or infiltration tunnel is an artificial tunnel that extends horizontally or at a slight inclination into the zone of saturation and through which water usually flows by gravity to the surface. Some tunnels are constructed

specifically for this purpose. Some abandoned ore tunnels or mine-drainage tunnels in Pennsylvania are utilized successfully as infiltration galleries.

Dug wells.—Dug wells generally are practicable only in places where the material may be dug with a pick and shovel and does not cave readily, and where the water table lies close to the surface. Dug wells commonly are curbed with wood, brick, tile, concrete, or dry rubble masonry, and should be water-tight for some distance below the surface and tightly covered to exclude surface water and drainage. They are poorly adapted to material that caves readily, such as fine sand, but owing to their large storage capacity they may be effective in recovering small supplies of water from poor water-bearing material such as glacial till. Generally it is not practicable to dig wells much below the water table, hence they are likely to fail in dry weather.

Caisson wells.—Caisson wells, which are generally larger than ordinary dug wells and may be 30 feet or more in diameter, are adapted to the recovery of large supplies of water from unconsolidated sand or gravel, such as glacial outwash. Construction involves the laying of a circular cutting shoe of wood, metal or concrete; the erection thereon of a casing of porous concrete or other suitable material; and the excavation of the material within the casing. As material is excavated, the casing sinks of its own weight or may be forced down, and as the excavation continues additional sections of casing are added until the desired depth is reached. Properly constructed caisson wells provide large storage capacity and large infiltration area, but generally are more costly than drilled wells.

Driven wells.—Small supplies of water may be obtained from shallow water-bearing sand or gravel by means of driven wells that may be from 1¼ to 3 inches in diameter. A short section of threaded pipe, to which is attached a pointed screen or strainer, is driven into the ground with a maul or sledge, and additional lengths of pipe are attached until the desired depth is reached. Their depth is limited by frictional resistance or by hitting large boulders.

Drilled wells.—Drilled wells probably are best suited to the conditions encountered in most parts of the State, in most types of rock, and for the recovery of large or small supplies of water. Most of the drilled wells in Pennsylvania, including all that penetrate the hard rock formations, are put down by the cable-tool percussion method, which employs a heavy chisel-edged drill bit or other tool suspended by a rope or cable to which a reciprocating motion is imparted by the drilling machine. The drill crushes the rock into small fragments and churns it into suspension in the water that is poured into the well, if water is not encountered in the formation that is being drilled. At intervals the drilling cuttings and sludge are removed from the hole with a bailer or sand pump. Small portable rigs are adapted for drilling wells 200 to 1,000 feet deep, and somewhat larger rigs, such as are used for drilling oil wells, are capable of drilling to depths of several thousand feet—even in hard rock. Drilled water wells range in diameter from 4 to 12 inches or more, but wells for domestic use are commonly 6 inches in diameter.

Wells drilled in consolidated rock formations are partly cased with oil-well or screw-joint casing to prevent caving of loose rock and to keep out surface water or undesirable ground water. The casing is generally driven down to an impervious layer, such as shale, below which the hole is left uncased to allow entrance of water from the porous or fractured rock. Such wells are known as open-end wells.

Some wells in unconsolidated sand or gravel are drilled and cased in the above manner, but in such material it is generally necessary to employ a suitable well screen or strainer. The purpose of the well screen is to hold back the coarse material in the formation and to permit the finer particles of material to pass through and be removed during the development process. This type of construction allows the water to percolate freely into the well and is especially necessary if a large supply of water is desired.

Drilled wells of large diameter, 24 to 60 inches, are commonly used in recovering large supplies of water from sand or gravel, and generally are not drilled by percussion methods, but are excavated by means of an orange-peel bucket, by the California mud-scow method, or by hydraulic rotary method. Wells of this type employ screens or slotted casing opposite the water-bearing material, and because of the low entrance velocity occasioned by their large diameter, are capable of yielding large supplies of water without "pumping sand." In places where large supplies of water are sought from materials not sufficiently coarse to be held back by the screen, a layer of coarser material may be placed around the screen either artificially or by pumping out the finer particles of the water-bearing materials, leaving a residual layer of natural gravel. Most so-called gravel-wall or gravel-packed wells in Pennsylvania are constructed by first drilling a somewhat larger hole (30 to 60 inches in diameter) and temporarily casing to the bottom; an inner screen and casing of smaller diameter is lowered into place; the annular space between the two casings is filled with selected gravel of uniform texture; and the outer casing is withdrawn all or part way. The effective diameter of the well is thus greatly increased by the layer of gravel which itself acts as a screen to reduce the entrance velocity and permit the entrance of large supplies of water.

Special methods of constructing, developing, and casing wells are sometimes employed. In some places, particularly in regions underlain by coal, it may be necessary to case wells to a considerable depth in order to case off beds of coal or other material that contain water of undesirable quality. In some wells two or more strings of casing are set, and cement is placed between successive strings in order to protect the inner casing from corrosive water—such as the acid water associated with coal seams in mining regions. Dry or weak wells in limestone sometimes may be salvaged and made to produce more water by "shooting" with a suitably placed charge of explosives. The explosion cracks the rock and opens up fractures that may lead to a nearby water-filled solution channel.

Methods of lift and types of pumps.—Many types of pumps and other lifting apparatus have been devised for mechanically withdrawing water from wells. Water is obtained from most of the dug wells

and some of the drilled wells by means of hand-operated lift pumps or force pumps. Some pumps of this type are operated by windmills or connected to gasoline engines or electric motors by means of pump jacks. Many modern rural homes have small pneumatic systems, in which a small electrically-driven force or suction pump forces water into a sealed tank against air pressure, and stops pumping when a certain pressure is attained. The air pressure forces water to any part of the house, and the pump starts automatically whenever the pressure falls below a fixed amount. Driven wells and some shallow dug wells commonly are equipped with hand-operated pitcher pumps. Some dug wells are equipped with hand-operated chain pumps or bucket pumps, and some have merely a windlass and bucket.

Most of the older municipal and industrial drilled wells and a few domestic wells are equipped with single- or double-action force pumps installed in the well or suction pumps at the surface, driven by electricity, steam, or internal combustion engines. Some wells are pumped by air lift, although many air-lift pumps have been replaced by modern pumps, owing to the inefficiency of the air-lift system. In this method compressed air is forced through a nozzle submerged some distance below the water level, and the resulting mixture of air and water being of less density than water alone, is carried to the surface and discharged.

Most of the newer industrial and municipal wells are equipped with electrically driven centrifugal or turbine pumps. The advent of these modern highly efficient pumps has greatly increased the yield from large wells and has greatly reduced the cost of pumping large supplies of water. Many of the old-style reciprocating pumps or air lifts are being replaced by centrifugal or turbine pumps. Centrifugal pumps are mounted at the surface or in pits and can be used only where the depth to water plus the draw-down does not exceed the working suction limit. Turbine pumps comprise a series of small connected turbines called bowls or stages (the number of such units depending on the height the water must be forced) that are placed at or below the water level and are connected by a vertical shaft to a vertical motor or pulley at the top. With a suitable number of stages a turbine is capable of forcing water to heights of several hundred feet.

PROBLEMS CONCERNING GROUND-WATER SUPPLIES

This report is intended merely as a general guide to the ground-water resources of Pennsylvania—their source, occurrence, character, development, and utilization. Many and varied problems are constantly arising in regard to the development of ground-water supplies of specific quantity and quality in different parts of the State and for many different uses. For the possible solution of such problems the reader is referred to: (1) the six bulletins published by the Pennsylvania Geological Survey (fig. 1), which contain a wealth of information in regard to ground-water supplies in all parts of the State; (2) the State Geologist, Topographic and Geologic Survey, Harrisburg, to whom many inquiries are addressed in regard to specific ground-water problems; and/or (3) competent well drillers who are

thoroughly familiar with ground-water conditions in the areas in which they operate. Some of the more important problems that arise often are mentioned below.

The sanitary location and protection of wells is highly important to the health and welfare of any community. Dug wells are likely to be unsanitary, especially in thickly settled communities without sewer systems. Properly constructed drilled wells are generally less subject to contamination than dug wells and springs, but great care should be exercised to protect every well and spring used for domestic or public supply from pollution by organic material. Wells should be so situated as not to receive drainage or seepage from the vicinity of buildings, barns, privies, or cesspools, and should be properly sealed at the top to keep out all surface water. Springs used to supply drinking water also should be protected by suitable walls or covers, but in spite of these precautions some springs—particularly in limestone—are likely to be contaminated at the points where water enters the underground reservoir.

Questions are constantly raised by individuals, industries, and municipalities as to where and at what depth, in a given locality, a supply of ground water can be obtained of adequate quantity and suitable quality. As discussed in preceding pages, the answer to such questions depends largely upon the geology, which in general is complicated.

New industries that require large quantities of water, such as rayon mills, want to know where large supplies of good water can be obtained. In past years many industries were located with regard to plentiful supplies of fuel or raw materials, but without particular regard to the quantity or quality of water available. Many such industries subsequently found themselves short of water and were forced to pipe water long distances or move to more favorable locations. Nowadays the availability of a good water supply is one of the first considerations in planning most industrial developments. Some industries require water that is very clear and free of iron, others require soft water, but some that use water only for cooling purposes require merely that the quantity be adequate.

In recent years the use of ground water for air-conditioning has steadily increased—particularly in large cities. In some places the pumping of many wells for air-conditioning may be taxing the capacity of the underground reservoirs. Wherever large quantities of ground water are pumped, detailed studies should be made in order to determine the safe yield of the ground-water reservoir. Such studies include the collection of records of current pumpage and periodic measurements of water levels in wells in order to determine whether pumping from wells is causing a serious decline in ground-water levels and hence in the quantity of water stored in the reservoir. Where the use of ground water for cooling purposes is heavy it may become necessary to return the water underground instead of wasting it.